



## King's Research Portal

DOI:

[10.1016/j.jpedsurg.2016.02.093](https://doi.org/10.1016/j.jpedsurg.2016.02.093)

*Document Version*

Peer reviewed version

[Link to publication record in King's Research Portal](#)

*Citation for published version (APA):*

Burdall, O. C., Makin, E., Davenport, M., & Ade-Ajayi, N. (2016). 3D Printing to Simulate Laparoscopic Choledochal Surgery. *Journal of Pediatric Surgery*. <https://doi.org/10.1016/j.jpedsurg.2016.02.093>

### **Citing this paper**

Please note that where the full-text provided on King's Research Portal is the Author Accepted Manuscript or Post-Print version this may differ from the final Published version. If citing, it is advised that you check and use the publisher's definitive version for pagination, volume/issue, and date of publication details. And where the final published version is provided on the Research Portal, if citing you are again advised to check the publisher's website for any subsequent corrections.

### **General rights**

Copyright and moral rights for the publications made accessible in the Research Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognize and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the Research Portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the Research Portal

### **Take down policy**

If you believe that this document breaches copyright please contact [librarypure@kcl.ac.uk](mailto:librarypure@kcl.ac.uk) providing details, and we will remove access to the work immediately and investigate your claim.

# Accepted Manuscript

## 3D Printing to Simulate Laparoscopic Choledochal Surgery

Oliver C. Burdall, Erika Makin, Mark Davenport, Niyi Ade-Ajayi

PII: S0022-3468(16)00209-8  
DOI: doi: [10.1016/j.jpedsurg.2016.02.093](https://doi.org/10.1016/j.jpedsurg.2016.02.093)  
Reference: YJPSU 57639

To appear in: *Journal of Pediatric Surgery*

Received date: 21 January 2016  
Accepted date: 7 February 2016



Please cite this article as: Burdall Oliver C., Makin Erika, Davenport Mark, Ade-Ajayi Niyi, 3D Printing to Simulate Laparoscopic Choledochal Surgery, *Journal of Pediatric Surgery* (2016), doi: [10.1016/j.jpedsurg.2016.02.093](https://doi.org/10.1016/j.jpedsurg.2016.02.093)

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

# 3D PRINTING TO SIMULATE LAPAROSCOPIC CHOLEDOCHAL SURGERY

Oliver C Burdall: MRCS Senior Clinical Fellow, King's College Hospital, London

Erika Makin FRCS(paed): Consultant Pediatric Surgeon, King's College Hospital, London

Mark Davenport ChM FRCS(paed): Consultant Pediatric Surgeon, King's College Hospital, London

Niyi Ade-Ajayi MPhil FRCS: Consultant Pediatric Surgeon, King's College Hospital, London

Corresponding Author:

Niyi Ade-Ajayi

Department of Paediatric Surgery

King's College Hospital

Denmark Hill, London SE5 9RS

England

E-Mail: [adeajayi@doctors.org.uk](mailto:adeajayi@doctors.org.uk)

Telephone: +44 203 299 3350

Fax: +44 203 299 4021

Oxford Level of Evidence - 4

Conflicting Interests and Declaration:

There are no conflicting interests to declare. The costs of 3-dimensional printing were met from the Pediatric Surgery Professorial Research Fund, King's College Hospital NHS Trust.

The authors do not have a financial relationship with any 3-dimensional printing companies.

## Abstract

### Aims of the Study:

Laparoscopic simulation has transformed skills acquisition for many procedures. However, realistic non-biological simulators for *complex* reconstructive surgery are rare. Life-like tactile feedback is particularly difficult to reproduce. Technological innovations may contribute novel solutions to these shortages. We describe a hybrid model, harnessing 3D technology to simulate laparoscopic choledochal surgery for the first time.

### Methods:

Digital hepatic anatomy images and standard laparoscopic trainer dimensions were employed to create an entry level laparoscopic choledochal surgery model. The information was fed into a 3D systems project 660pro with visijet pxi core powder to create a free standing liver mould. This included a cuboid portal in which to slot disposable hybrid components representing hepatic and pancreatic ducts and choledochal cyst. The mould was used to create soft silicone replicas with T28 resin and T5 fast catalyst. The model was assessed at a national pediatric surgery training day.

### Results:

The 10 delegates that trialed the simulation felt that the tactile likeness was good (5.6/10 +/- 1.71, 10=like the real thing), was not too complex (6.2/10 +/- 1.35; where 1=too simple, 10=too complicated), and generally very useful (7.36/10 +/- 1.57, 10=invaluable). 100% stated that they felt they could reproduce this in their own centres, and 100% would recommend this simulation to colleagues.

### Conclusion:

Though this first phase choledochal cyst excision simulation requires further development, 3D printing provides a useful means of creating specific and detailed simulations for rare and complex operations with huge potential for development.

**Keywords:** 3-dimensional printing; Surgical Simulation; Choledochal cyst excision

## Introduction

Since the first laparoscopic training programmes were described in the early nineties [1], there has been a huge amount of research into the potential benefits of practicing laparoscopic skills outside of the operating theatre [2-5]. Although clinical benefit was a presumed effect of ex vivo skills training [2], until recently there had been a lack of high quality studies demonstrating transference of these skills to the theatre [3]. A recent systematic review by Zendejas looked at 219 comparative studies, with 151 (69%) of these comparing skills training intervention against no intervention. This showed benefits of simulation based laparoscopic surgery and has contributed to a shift in thinking; not whether minimal access skills training should be provided as part of standard surgical training but how to provide it most effectively [4,5]. This is particularly true in pediatric surgery in which a range of relatively rare but complex surgical interventions are called for. Reconstructive procedures pose a specific problem when considered alongside workforce expansion and the dilution of expertise. The result is limited training opportunities for even more senior trainees which makes the role of surgical simulation even more important. However, problems remain with ensuring that simulation is realistic, affordable and has construct validity. Advances in virtual reality simulation have led to the development of built in resistance arms to provide haptic feedback [6]. While the technology has improved significantly over the years, problems remain with image production, poor trainer reviews and expense. Meanwhile, laparoscopic box trainers have become much more widely available for trainees [7].

Realistic, non-biological simulators for complex reconstructive surgery are still uncommon. The relatively new, and rapidly advancing, technology of 3-dimensional printing has already been used to address some surgical service issues. Though only described in a medical context a little over a decade ago, the technology has moved from merely providing modeling of specific patient anatomy, based on CT/MRI imaging, to allow operative planning [8,9]. In the non-uniform world of pediatric surgery, where sizes, shapes and anatomy vary through age ranges and congenital abnormalities, the ability to design interventions for the specifics of that patient carries huge potential. In 2013, Zopf described the successful use of a 3D printed model of a pediatric patient to treat their tracheobronchiomalacia.

Despite these advances, there have been limited descriptions of 3D printing being used to create accurate simulations of complex and rare procedure, such as laparoscopic choledochal

cyst excision. We aimed to develop and trial a model of laparoscopic choledochal cyst excision.

## Methods

The authors worked in conjunction with a local 3D printing and design company, *Cadventure*, to produce an entry level laparoscopic choledochal surgery model, using digital hepatic anatomy images and standard laparoscopic trainer dimensions. This creates a CAD file which is then split into 2D layers which can be used by a standard commercially available Selective Laser Sintering printer (3D systems project 660pro). Due to the current expense of 3D printing, a free-standing liver mould was created using a nylon-based powder (visijet pxl core powder) at a cost of £900; which included consultation fees and prototyping (see figure 2). The design included a cuboid portal in which to slot disposable hybrid components representing hepatic and pancreatic ducts and choledochal cyst. (Figure 1).

The single printed mould was then used to create multiple models using T28 silicone mould rubber, which was deemed to have the most appropriate consistency and flexibility in prototype phase. This was combined with a standard T5 fast catalyst (1: 20 Catalyst:Silicone). This was poured into the mould coated with *Ambersil Formula 5 Silicone release* spray to allow for product release once set. Once left for 3 hours, the model was removed and trimmed of excess silicone (Figure 2). Silicone and catalyst for 4 models with our dimensions costs £40 at a standard retailer.

The cuboid portal was then filled with a disposable and reusable simulated biliary tree. This comprised a square sponge with balloon embedded within in, a surgical glove finger to simulate the dilated proximal ducts and an electrical wire insulating tube to represent the common bile and pancreatic ducts (Figure 1).

The model was trialed at the Karl Storz/ British Association of Pediatric Endoscopic Surgeons (BAPES) laparoscopic skills national training day. The session consisted of a 20 minutes simulated excision focusing on four key steps: i) active traction and then division of the common bile duct; ii) dissection of the balloon cyst from the sponge bed; iii) internal visuali-

sation of the upper limit of the cyst and the duct level and iv) transaction of the cyst and hybrid anastomosis with porcine oesophagus as the simulated roux loop (Figure 3).

Feedback was then collected from delegates on three key areas using visual analogue scores: tactile feedback, usefulness and complexity. Yes/no responses were collected as to whether they thought they could replicate this in their own centres and whether they would recommend this model to colleagues. Space was also left on the form for free text qualitative feedback.

## Results

Twenty senior pediatric surgical trainees attended the national training day. The biliary station comprised two parts: simulated laparoscopic cholecystectomy with porcine organs and the choledochal cyst simulation as described. Ten delegates trialed the latter simulation. Feedback was collected from all 10.

On visual analogue scoring the simulation scored a mean of 5.6/10 (range: 3-8; SD 1.71), where 10 signified it feeling like the real operation and 1 was nothing like it. The delegates felt the complexity was about right scoring it a mean 6.2/10 (range: 4-8; SD 1.35), where 1 = too simple and 10 = too complicated. The simulation was also felt to be very useful overall with a mean of 7.36/10 (range: 4-9; SD 1.57), where 1=useless and 10=invaluable (see figure 4). All delegates felt that it was easily reproducible in their own units and 100% also stated they would recommend the simulation to their colleagues.

## Discussion

The trainees that attended the national training day were there by invitation from BAPS following recommendation from their individual departments. They were senior pediatric surgery trainees with an interest in minimal access surgery. Despite this, none had ever used a laparoscopic choledochal cyst excision simulation before. To the authors' knowledge this is the first described simulation of this uncommonly performed, complex procedure. This first phase model received globally positive feedback; in which it was described as not overly complicated, realistic and useful to trainees. All delegates that used it stated that they would

recommend it as a valuable training tool. They also stated that they felt it could be reproduced in their departments, thus achieving the goal of producing a simple, effective and reproducible entry level simulation model for the condition.

As expected from the first trial, the feedback from the delegates highlighted a few issues with the phase 1 model we had created. Three of the delegates specifically identified issues with the adhesive used to stick the balloon cyst into the sponge bed. The issue was a balance between being able to dissect it off in the allocated time and it not coming away too easily. Time pressure was also raised as an issue by delegates. The 4 step simulation was given a 20 minute slot in the all day skills workshop. This meant that ultimately, none of the delegates completed a full anastomosis. Despite this, the delegates felt this was a useful and realistic simulation, with one writing “this is a useful model for simulating the task and its ergonomic challenges”. In order to address these issues we are trialing different adhesive options; including velcro and a range of base materials. The time recommended for future workshops has also increased to allow for completion of all steps. The authors have also discussed options of creating of a 3D printed mould to create an entirely 3D printed model in thin, malleable silicone, with the hospitals own 3D printing department. A model for pyeloplasty created in this way has already been trialed by Cheung et al (2014) which included a synthetic kidney, ureters and renal pelvis. Theirs were also produced from a 3D printed solid mould in order to allow quick production of multiple models using Dragon-skin rubber. Both delegates and experts at their trial gave positive reviews for likeness to the real thing and usefulness of the simulation [14].

A number of other authors have also speculated on the potential for 3D printing in teaching and training after successfully producing accurate models of complex or rare anatomy [15-17]. These models have allowed operative planning in urology, specifically renal transplants, neurosurgery and cardiothoracics. In particular, parallels for pediatric surgery can be drawn from the latter two specialities; they have utilised 3D printing technology in order to recreate procedures that require practice but have limited training opportunities, such as berry aneurysm clipping and cardiac procedures that have been reduced in frequency by the advent of endovascular surgery [16,17].



The pediatric surgical training curriculum in both North America and UK define key procedures at each level of training [18,19]. The more basic procedures, such as pyelomyotomy and appendicectomy, have many effective low fidelity simulations which have led to their inclusion in logbooks and training schemes. However, there are few described, reproducible simulations for the more complex surgeries for more senior trainees; such as tracheoesophageal fistula, biliary atresia or choledochal cysts. The anatomy of these procedures is more complex and the procedures have a larger number of steps. The accuracy of 3D printing to recreate anatomy from layer imaging and its application as an educational tool is being increasingly reported [20]. Choledochal cysts can present with great variation, even outside of the broad 4-part classification [21]. In such situations 3D printing could allow more high fidelity, patient specific practice and operative planning prior to surgery, to the benefit of even the most experienced surgeons. This had previously been described in the case of complex tumours, such as perihilar cholangiocarcinomas [22]. The benefits of practicing immediately prior to surgery, or 'warm up surgery', even for routine cases or tasks have been shown by two recent randomised control trials [23,24]. Between the two studies, a total of 540 surgeons were split into no warm up vs warm up groups, which showed significantly better performance on predetermined scoring systems not only on simulation but also in the operating theatre proper [23,24].

This potential could be stretched yet further as 3D printing utilises bio-scaffolds to produce actual tissue, or replica tissue, constructed in a process termed bioprinting [25-27]. Though little published research has identified the use for this very new technology in simulation training, this opportunity has already been commercially recognised. This technology is primarily aimed at mass-producing patient specific organs for transplant, but this goal is still some way off [26]. Nonetheless, replica organs with the same consistency and tissue mechanics of actual viscera have already been produced and on the market for use as training aids. These can even be injected with dye to simulate bleeding when cut [27].

## Conclusion

Although 3D printing remains relatively expensive for the specific item; the production of a 'one off' mould allows for ongoing production of future samples at a more affordable price. 3D printing provides a useful means of creating specific and detailed simulations for rare and complex operations with huge potential for development. Further modifications of this

prototype model, as well as further research into this field, is required in order to tap into the potential for this new technology as a teaching aid.

#### References:

1. Bailey RW, Imbembo AL, Zucker KA. Establishment of a laparoscopic cholecystectomy training program. *Am Surg* 1991; 57(4):231-6
2. Dunkin B, Adrales GL, Apelgren K, Mellinger JD. Surgical simulation: a current review. *Surg Endosc* (2007) 21:357-366
3. Sturm LP, Windsor JA, Cosman PH, et al. A systematic review of skills transfer after surgical simulation training. *Ann Surg* 2008;248:166-179
4. Zendejas B, Brydges R, Hamstra SJ and Cook DA. State of the evidence on simulation-based training for laparoscopic surgery. A systematic review. *Annals of surgery* 2013;257:586-593.
5. Selzer DJ and Dunnington GL. Surgical skills simulation; a shift in the conversation. *Ann of surgery* 2013;257(4);594-5.
6. Salkini Mw, Doarn CR, Kiehl N, et al. The role of haptic feedback in laparoscopic training using the LapMentor II. *J Endourol*. 2010 Jan;24(10):99-102
7. Singapogu R, Burg T, Burg KJ, et al. A perspective on the role and utility of haptic feedback in laparoscopic skills training. *Crit Rev Biomed Eng*. 2014;42(3-4):293-318
8. Makert M, Weber S, Lueth TC. A beating heart model 3D printed from specific patient data. *Conf Proc IEEE eng Med biol Soc*. 2007;2007:4472-5
9. Sodian R, Schmauss D, Markert M. et al Three-dimensional printing creates models for surgical planning of aortic valve replacement after previous coronary bypass grafting. *Ann Thorac Surg*. 2008 jun;85(6):2105-8

10. Gretsche KF, Lather HD, Peddada KV, et al. Development of novel 3D-printed robotic prosthetic for transracial amputees. *Prosthet Orthot Int*. 2015 May 1.
11. Melican MC, Zimmerman MC, Dhillon MS, et al. Three-dimensional printing and porous metallic surfaces: a new orthopedic application. *J Biomed Mater Res*. 2001 May;55(2):194-202
12. Xu, Binder KW, Albanna MZ, et al. Hybrid printing of mechanically and biologically improved constructs for cartilage tissue engineering applications. *Biofabrication*. 2013 Mar; 5(1):015001
13. Zopf, Nelson, Ohye. Bioresorbable Airway Splint Created with a Three-Dimensional Printer. *n engl j med* 368;21
14. Cheung CL, Looi T, Lendvay TS, Drake JM et al. Use of 3-dimensional printing technology and silicone modelling in surgical simulation: development and face validation in pediatric laparoscopic pyeloplasty. *J Surg Educ*. 2014;71(5):762-7
15. Abila AA and Lawton MT. Three-dimensional hollow intracranial aneurysm models and their potential role for teaching, simulation and training. *World Neurosurg*. 2015 Jan;83(1):35-6
16. Kusaka M, Sugimoto M, Fukami N et al; Initial experience with a tailor-made simulation and navigation program using a 3-D printer model of kidney transplantation surgery. *Transplant Proc*. 2015 Apr;47(3):596-9
17. Kurenov SN, Ionita C, Sammons D and Demmy TL. Three-dimensional printing to facilitate anatomic study, device development, simulation and planning in thoracic surgery. *J Thorac Cardiovasc Surg*. 2015 Apr;149(4):973-979.
18. American Association of Pediatric Surgeons; pediatric surgery training curriculum; [HTTP://WWW.EAPSA.ORG/APSA/MEDIA/DOCUMENTS/CURRICULA/APSTPDCURRICULUM.PD](http://www.eapsa.org/apsa/media/documents/curricula/apstpdccurriculum.pdf)  
F - accessed Nov 2015

19. British Intercollegiate Surgical Curriculum Programme; Pediatric Surgery Key Procedures: [HTTPS://WWW.ISCP.AC.UK/SURGICAL/SPECIALTYSYLLABUS.ASPX?STAGE\\_ID=1209&SPEC\\_ID=132&TAB=STAGES](https://www.iscp.ac.uk/surgical/specialtysyllabus.aspx?stage_id=1209&spec_id=132&tab=stages) - accessed Nov 2015
20. Cortello JP, Oliviveri LJ. Incorporating three-dimensional printing into a simulation-based congenital heart disease and critical care training curriculum for resident physicians. *Congenital Heart Dis.* (2015). 10(2) 185:90.
21. Makin E, Davenport M. Understanding choledochal malformation. *Arch Dis Child.* 2012 Jan;97(1):69-72
22. Takagi K, Nanshima A, Abo T, et al. Three-dimensional printing model of liver for operative simulation in perihilar cholangiocarcinoma. *Hepatogastroenterology.* 2014 Nov-Dec;61(136:2315-6)
23. Chen CC, Green IC, Colbert-Getz JM, et al. Warm-up on a simulator improves residents' performance in laparoscopic surgery: a randomized trial. *Int Urogynecol J.* 2013 Oct;24(10):1615-22
24. Rosser JC, Genile DA, Hanigan K and Danner OK. The effect of video game "warm-up" on performance of laparoscopic surgery tasks. *JSLs.* 2012; 16(1):3-9
25. Yoo SS, 3D-printed biological organs: medical potential and patenting opportunity. *Expert Opin Ther Pat.* 2015 May;25(5):507-11
26. Murphy SV and Atala A. 3D bioprinting of tissues and organs. *Nature Biotechnology* (2014) 32, 773-785
27. 3D Printing Association Website:  
<https://www.the3dprintingassociation.com/news/post/3d-printed-organ-replicas-Mar-2015>.

**Figure Legends:**

Figure 1:

Nylon powder 3D printed mold at the top of the picture with the resulting silicone model beneath.

Figure 2:

3D printed hepatic base with cuboid portal for choledochal laparoscopic surgery simulation

Figure 3:

i) active traction and then division of the common bile duct; ii) dissection of the balloon cyst from the sponge bed; iii) internal visualisation of the upper limit of the cyst and the duct level and iv) transection of the cyst and hybrid anastomosis with porcine oesophagus as the simulated roux loop.

Figure 4:

Bar graph of means out of 10 from visual analogue scores for tactile feedback, complexity and usefulness of choledochal model: (10=exact likeness); complexity (1=too simple, 10=too complicated); and usefulness (10=invaluable).



Figure 1



Figure 2

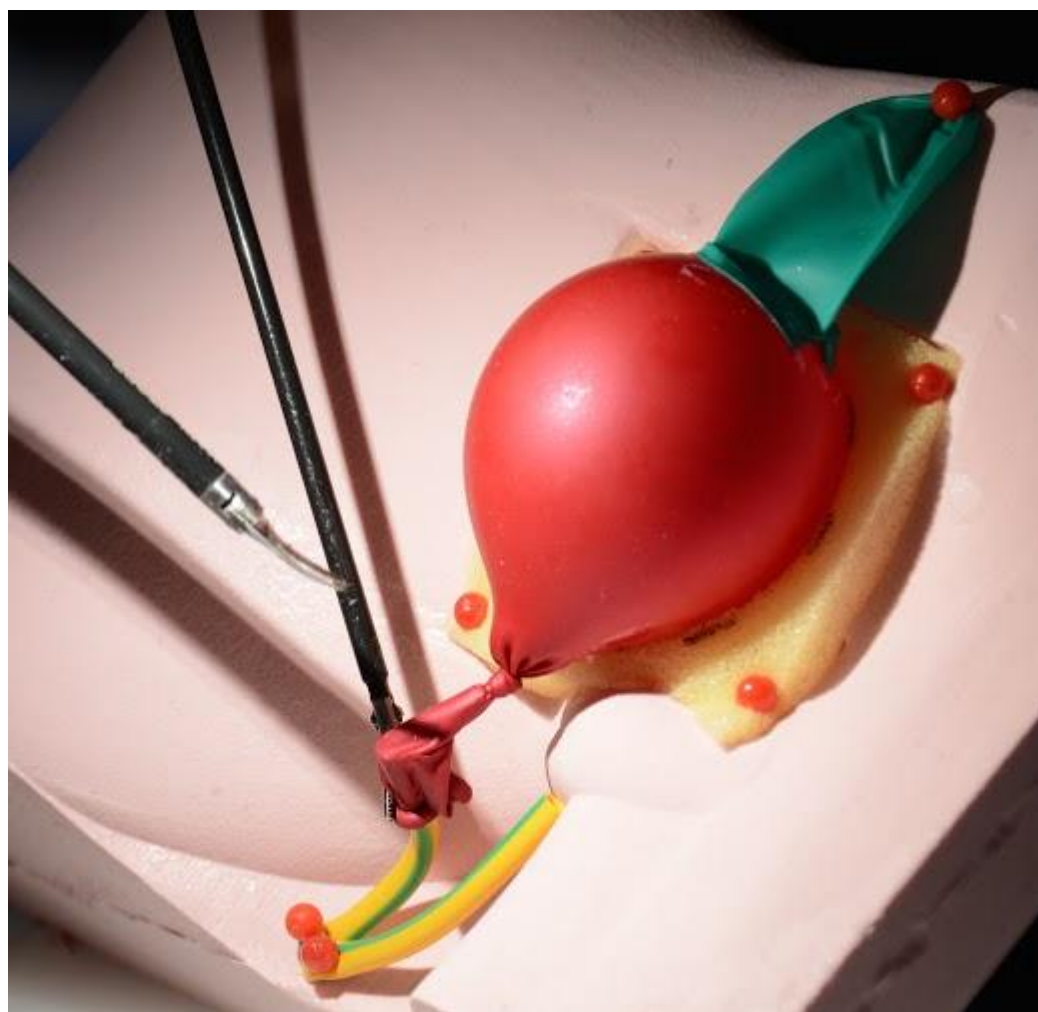


Figure 3i





Figure 3ii

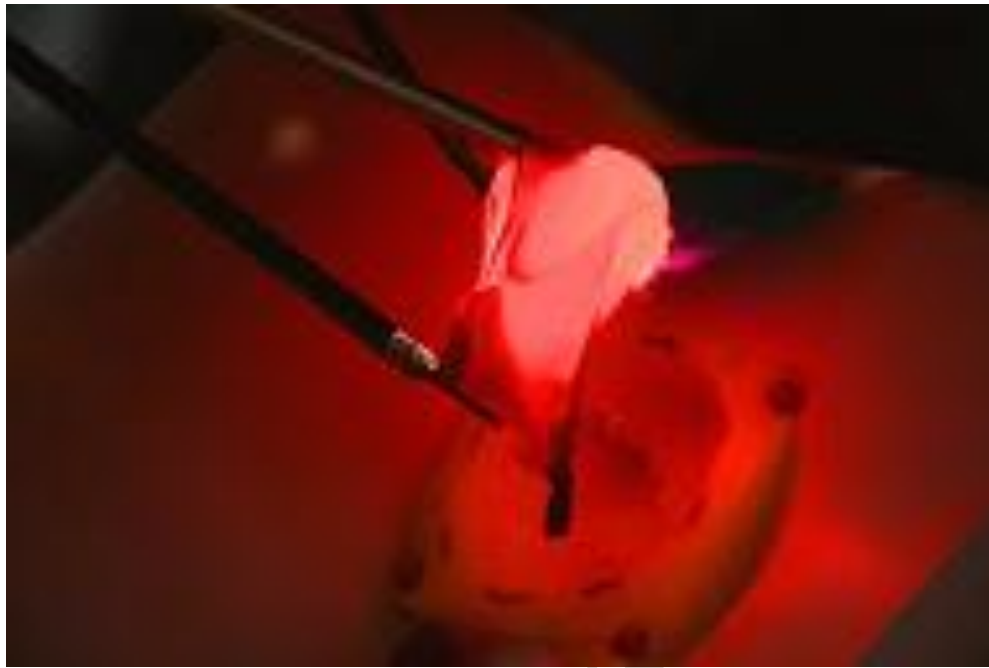


Figure 3iii

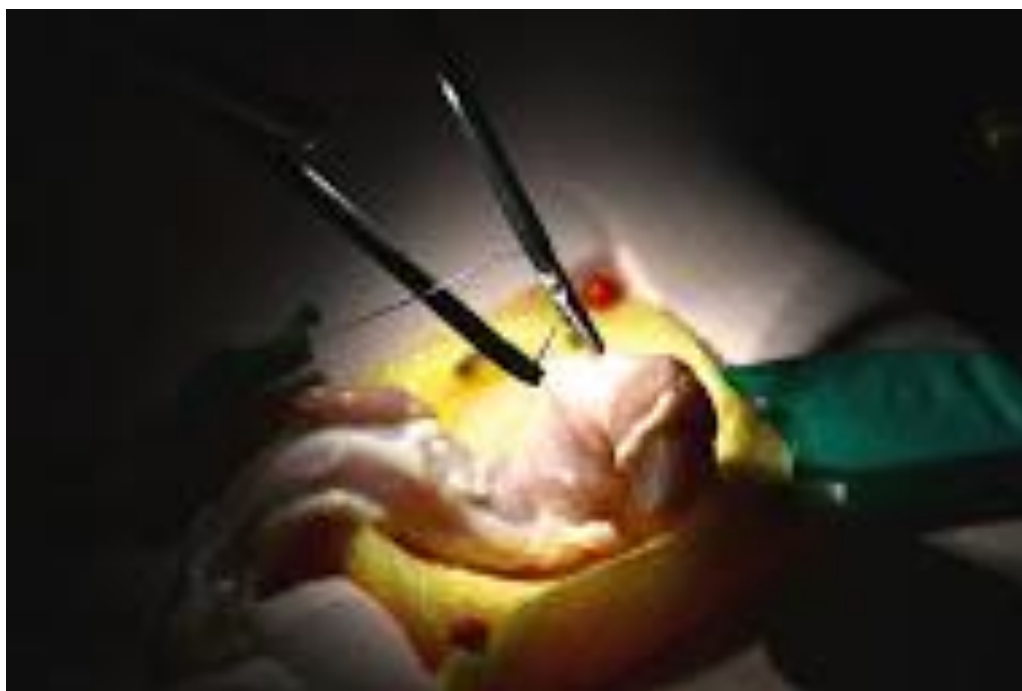


Figure 3iv

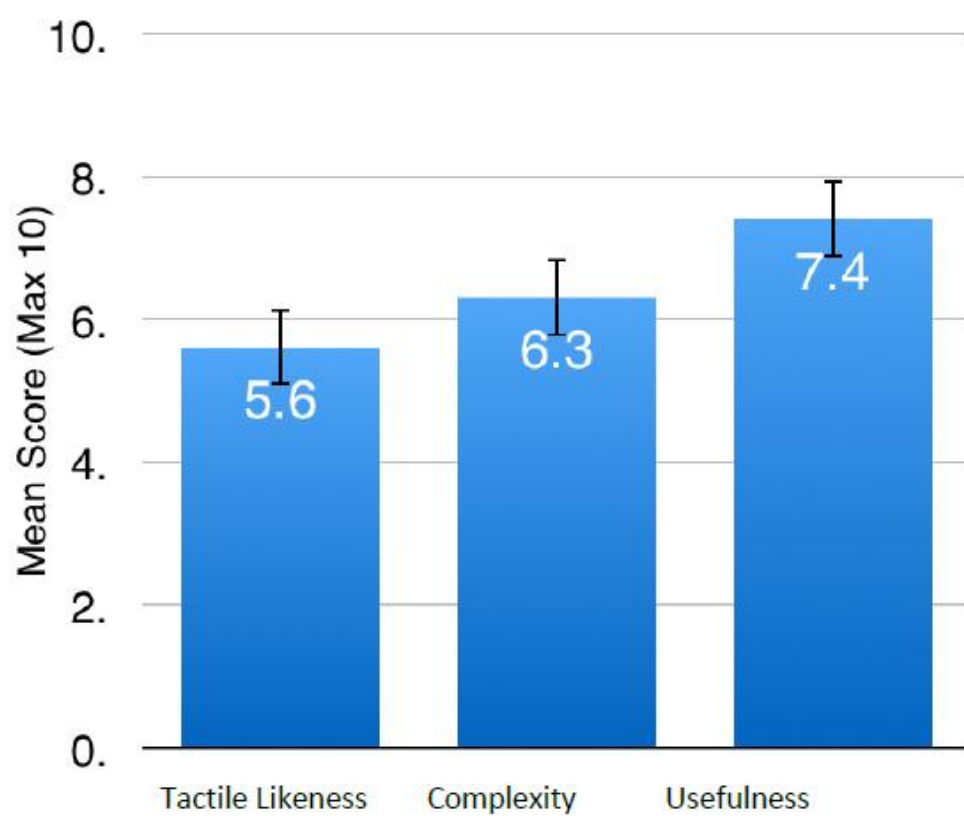


Figure 4